REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 31, 1996	Final Report, 12/01/92 - 11/30/95

4. TITLE AND SUBTITLE

Probabilistic Error Checkers

5. FUNDING NUMBERS

F49620-93-1-0082

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AFOSR-TR-96
0330

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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Bolling AFB, DC 20332

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19960624 240

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Abstract

This final report summaries the progress made in during the areas of research supported by AFOSR. During the contract,

- (a) the PI implemented and deployed two probabilistic error checkers, one for the domain name system and the other in an application that replicates FTP-servers;
- (b) the PI and his student Sugih Jamin developed a measurement-based admission control algorithm for real-time traffic over integrated services packet networks. This admission control algorithm can achieve double the performance of the competition's algorithm for voice, video, and self-similar traffic.
- (c) the PI, co-funded by ARPA, developed the Harvest hierarchical object cache for the Internet. The Harvest cache reduces network traffic from routine requests, improves object availability, and isolates the network from accidently looping requests. It is in use at several hundred sites across the Internet.

During the grant period, the PI won the NSF National Young Investigator (NYI) award and a 1993 USC innovative teaching award. His PhD student, Sugih Jamin, received the 1995 ACM SIGCOMM best student paper award for research co-funded by this AFOSR grant.

14. SUBJECT TERMS	15. NUMBER OF PAGES
computer networks, software engineering, network protocols, multi-media networks, network admission control, error detection	7
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Final Report– Probabilistic Error Checkers: F49620-93-1-0082

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Abstract

This final report summarizes the PI's research in three related areas of research: distributed system error detection, reliable internet software systems, and measurement-based admission control for guaranteed quality of service networks.

- the PI implemented, deployed, and maintained a probabilistic error checker (PEC) for the Domain Name System (DNS). He then re-applied the PEC concept to the design of a system to massively replicate databases around the Internet.
- The PI devised a measurement-based call admission control algorithm for real-time traffic over integrated services packet networks. This admission control algorithm achieve doubles the performance of the competition's algorithm for voice, video, and self-similar traffic.
- The PI, in collaboration with other agencies, applied his reearch to the design of the Harvest hierarchical Internet object cache. Besides reducing network traffic from routine requests, it improves object availability and isolates the network from accidently looping requests.

Objectives

This project developed techniques to build and debug robust, wide-area-network computer systems. The research addressed how to

- uncover hidden implementation errors in deployed software,
- isolate the effects of faulty nodes on wide-area-network performance,
- most efficiently use limited network bandwidth.

The PI developed tools to diagnose and resolve performance and design problems of heterogeneous, autonomously managed, distributed systems, focusing attention on key Internet components, including the Domain Name System (DNS) and the WWW, gopher, and FTP services.

The research was based on the premise that distributed systems fail in stereotypical ways: they deadlock, they fail half-way through an operation, their networks partition or exhibit asymmetric communication paths, their logic gets caught in loops. The PI tested that hypothesis that the way to make a robust, heterogeneous distributed system is to program its elements so that the components themselves exhibit this behavior right from the start. Applying his ideas to software prototypes, the PI demonstrated that when components of a distributed system occasionally mimic their own failure during normal service, that the system can be designed to diagnose implementation and design mistakes in other system components.

Summary of Research Effort

The PI his DNS checker and probabilistic error checker software and explored the probabilistic checker technique in the Harvest wide-area-network data replicator. He integrated the ideas behind checker into the Harvest Web cache. ISI is proposing to regain administrative control of the Internet's root name servers and deploy the PI's DNS checker software.

In a separate research thrust, he developed network conversation admission control algorithm for multi-media network applications.

Probabilistic Error Checkers

The first goal of this project was to create diagnostic software that identifies broken components of distributed services under normal service and occasionally

stress tests particular components to explore their behavior under duress. As an example of such software, the PI implemented a diagnostic tool for name server traffic. This checker program analyzed the interaction between a name server and its possibly mis-behaving clients.

The PI's probabilistic error checker for DNS demonstrates that a simple module can identify misbehaving components of a functioning distributed system by feigning death and do so without breaking the system. In contrast to the full DNS checker the probabilistic checker is significantly smaller, simpler, less memory demanding, but still capable of diagnosing broken components [2].

This software is deployed on a secondary of the ".us" domain and can be queried from *http://excalibur.usc.edu/research/checker*. The software and instruction manuals for the DNS checker software are available from *ftp://catarina.usc.edu/pub/danzig/home.html*.

Hierarchical Object Cache

The explosion of interest in the Internet information "Mosaic" has taxed the Internet's WWW, gopher, and FTP servers. Jointly with funding from Hughes information Systems (via a NASA subcontract) and directly from ARPA, the PI built the Harvest Object Cache, which is architecturally similar to DNS, but designed to avoid the flaws that uncovered in DNS [1]. The cache has lead to an international collaboration of several hundred users http://www.nlanr.net/Cache

When a referenced object causes a cache miss, the cache estimates its network distance to the object's home node and checks to see if the object would hit the cache's immediate parents and siblings. If the object's home node is closer than in any sibling or parent cache for which the object is a hit, the cache fetches the object directly. Otherwise, if the object is a miss in all siblings and parents, then the cache fetches the object through the closest parent cache. By closest cache, we mean the parent cache with shortest round trip time. An example cache topology is shown in Figure 1.

Real-Time, Multi-media Networks

The PI developed a measurement-based, conversation admission control algorithm for real-time, multi-media networks [4, 3]. The applies to integrated packet networks, whether IP or ATM. To provide real-time, multimedia services, the network must assign and reserve re-

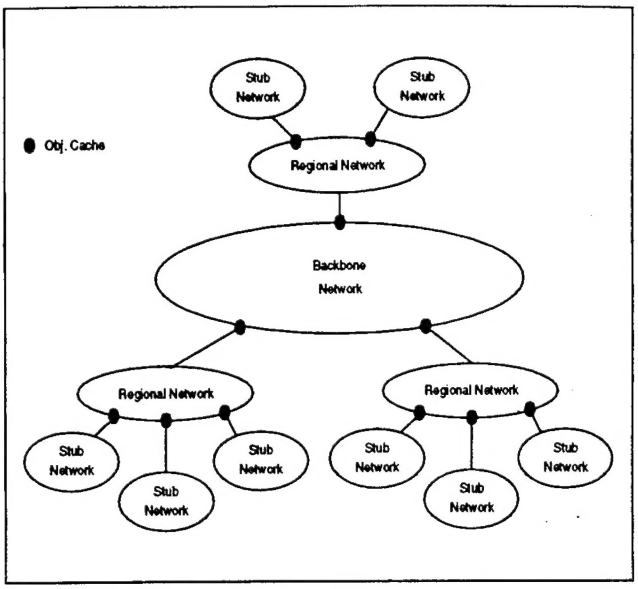

Figure 1: Hierarchical object cache for the Internet.

sources to users. While current IP and ATM networks do not yet have this infrastructure in place, they eventually will.

Existing admission control algorithms require that network users accurately specify their quality of service (QOS) requirements. The admission control algorithm then translates this QOS specification into bandwidth, buffer space, and switching priority reservations at each network switch and link.

The PI is currently developing a measurement-based admission control algorithm. The user still states his quality of service requirements, but the network measures the network's total resource usage and attempts to over-book the reservations, to increase network utilization. The admission control algorithm works with two classes of service: guaranteed service and predictive service. Guaranteed and predictive service, like the names imply, are comparable to hard and soft-real time systems. Guaranteed service reserves more resources than predictive service, but the network always meets requested QOS.

The goal of our admission control research, like our cache and replicator research, is to more efficiently use network bandwidth.

Personnel

The following students were funded by this AFOSR project:

- Steve Miller, who wrote the DNS checker,

- Charles Chan, who wrote the probabilistic error checker for DNS and who created the small-memory version of checker, is now employed at Motorola.
- Katia Obraczka, who recently completed her Ph.D. dissertation on "Massively Replicating Services in Wide Area Internetworks", now works at ISI.
- Erhyuan Tsai debugged our *mirrord* replication tool using a probabilistic error checker. Now works at Netscape.
- Anawat Chankhunthod and Chuck Neerdales worked on the hierarchical object cache. Chuck now works for Netscape. Anawat is still a PhD student.
- Sugih Jamin passed his Ph.D. thesis defenese on "A Measurement-based Admission Control Algorithm for Integrated Services Packet Networks". He won best student paper prize at SIGCOMM 95 and is now interview for faculty and research lab positions.

Awards

- received best-student paper award 1995 ACM SIGCOMM
- served on the 1993, 1995, & 1996 ACM SIGCOMM program committee
- served on the 1996 IEEE INFOCOMM program committee
- served on an NSF Networking Research Panel, December 1994 & March 1996
- served on the 1993 & 1996 ACM SIGMETRICS program committees
- received the NSF NYI award, 1994.
- Served as associate editor, Journal of Internetworking

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RESEARCH INTERESTS: Computer networks and Internet information systems.

EDUCATION

- Ph.D. in Computer Science, University of California at Berkeley, December, 1989. Dissertation Advisor: Domenic Ferrari.
- B.S. in Applied Physics, with highest honors, University of California at Davis, June 1982.

ACADEMIC EXPERIENCE

- Assistant Professor, Computer Science Department, University of Southern California. Since 1990.

AWARDS and HONORS:

- National Young Investigator (NYI), National Science Foundation, Sept 1994-1999.
- U.S.C. Innovative Teaching Award for creating CS402L 'Multimedia Operating Systems and Networks Laboratory', 1993. Awarded by the USC Innovative Teaching Committee.
- U.C. Berkeley Demetri Angelakos Service Award for assistance to fellow computer science graduate students, 1987.
- American Electronic Association Faculty Development Fellowship 1985-1989.
- Graduated with highest honors, U.C. Davis, June 1982. Distinction awarded to the best one percent of undergraduates.
- President's Undergraduate Fellowship, U.C. Davis, 1981-1982.

PROGRAM COMMITTEEs and REFEREEING:

- Associate Editor: Journal of Internetworking: Research and Experience, August 1994-present.
- Program Committees: IEEE INFOCOMM 1996, ACM SIGCOMM (1996,1995, and 1993), ACM SIGMETRICS (1993 and 1996).
- Panell Member for NSF Networking Research, December 1994, March 1996. Also referee proposals for NSF Networking research and NSF Operating Systems & Systems Software programs.
- Frequent referee for ACM SIGCOMM, ACM SIGMETRICS, ACM TOCS, ACM/IEEE Transactions on Networking, IEEE TSE (Partial List).
- University Library Committee 1992-1993. University Innovative Teaching Committee 1992-1993.
- Computer Science Department: Graduate Student Assistantship Committee 1993-1995, PhD Advising Committee 1995-

FUNDING:

- NSF, National Young Investigator, $275,000, 9/94-9/99.
- NIH, Human Brain Project. $4,500,000 in collaboration with Michael Arbib and 7 other USC faculty. 9/94-8/99.
- Hughes Aircraft "Object Caching and Bulk Transfer Protocols for EOSDIS, $95,000, 2/94-7/94
- ARPA "Resource Discovery", $432,000 subcontract of a $2,000,000 contract, 9/93-8/96
- USC Innovative Teaching Award. $6,600. 7/93-6/94.
- NSF Small Scale Infrastructure Grant. $1,076,000, 1/93-12/97 (In collaboration with Estrin, Ghandeharizadeh, Horowitz, Hull, and McLeod).
- U.S Army, SBIR consultant to ACSC, $20,000, 1/94-12/94
- Air Force Office of Scientific Research. $243,000, 12/92-11/95, "Probabilistic Error Checkers".
- Powell Foundation Instructional Equipment Grant. $21,000, 9/92-8/93, "Undergraduate Multimedia OS and Network Lab".
- Powell Foundation Instructional Equipment Grant. $21,000, 9/91-5/92, "Graduate Sudent Computing".
- USC Innovative Teaching Award. $6,000. 6/91-12/91.
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